



Light Leakage Reduction in the SuperCDMS & NEXUS Detector Systems

Jillian Gomez

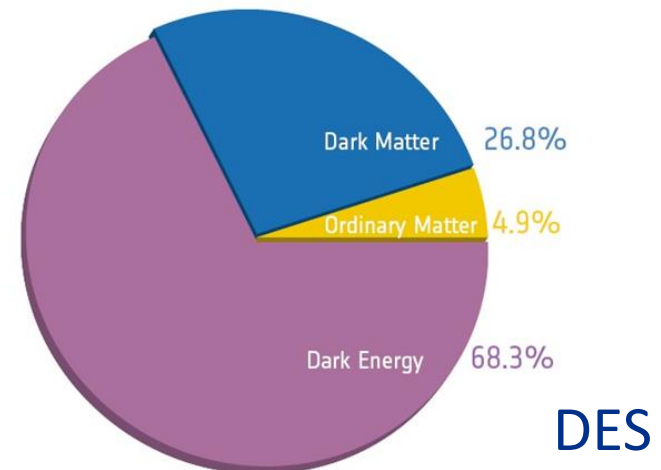
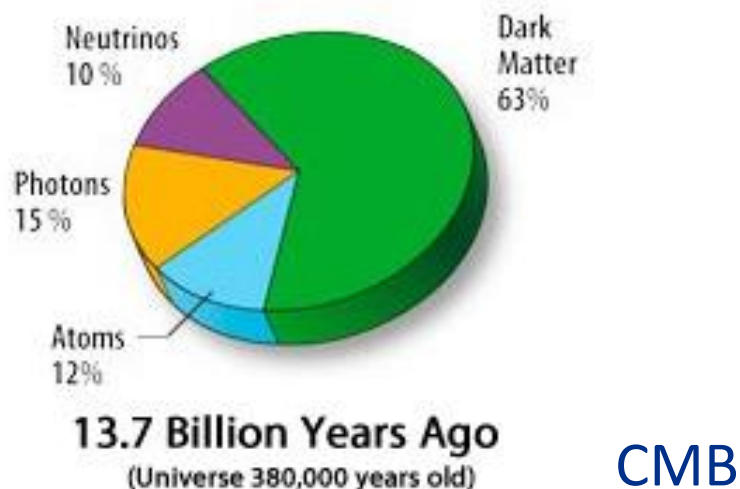
SIST Final Presentation

August 7, 2019

Dark Matter: “We know what it’s not.”

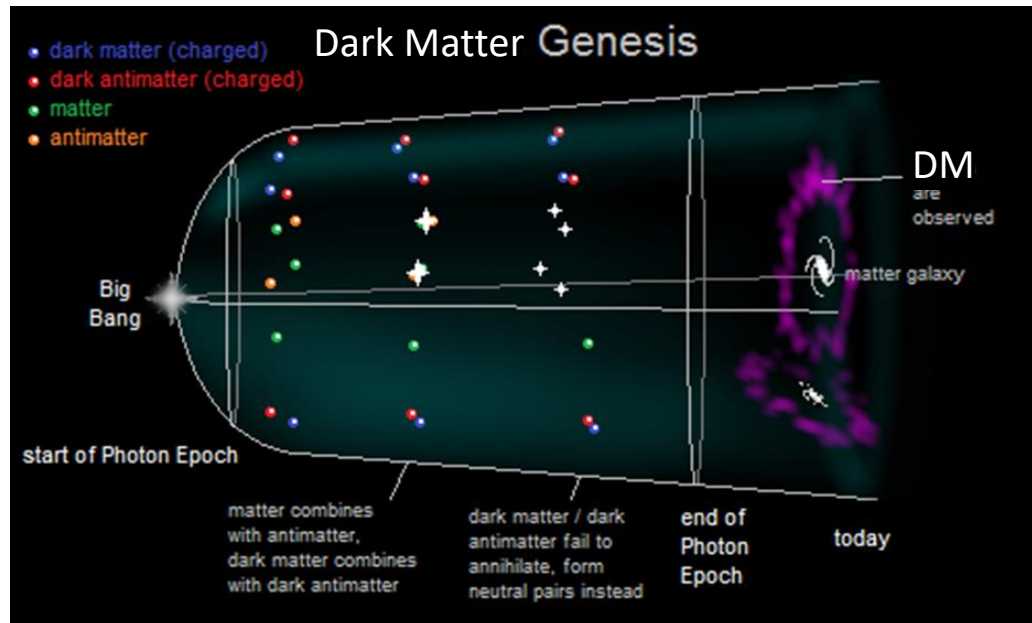
According to the latest astronomical observations, DM makes up 85% of all matter, yet we still do not have a particle to identify it as.

- Some things we know:
 - DM has only been observed through gravitational interactions.
 - Dark Matter is not Antimatter (annihilates matter on contact)
 - Dark Matter is not Black Holes (more lensing events than actual)

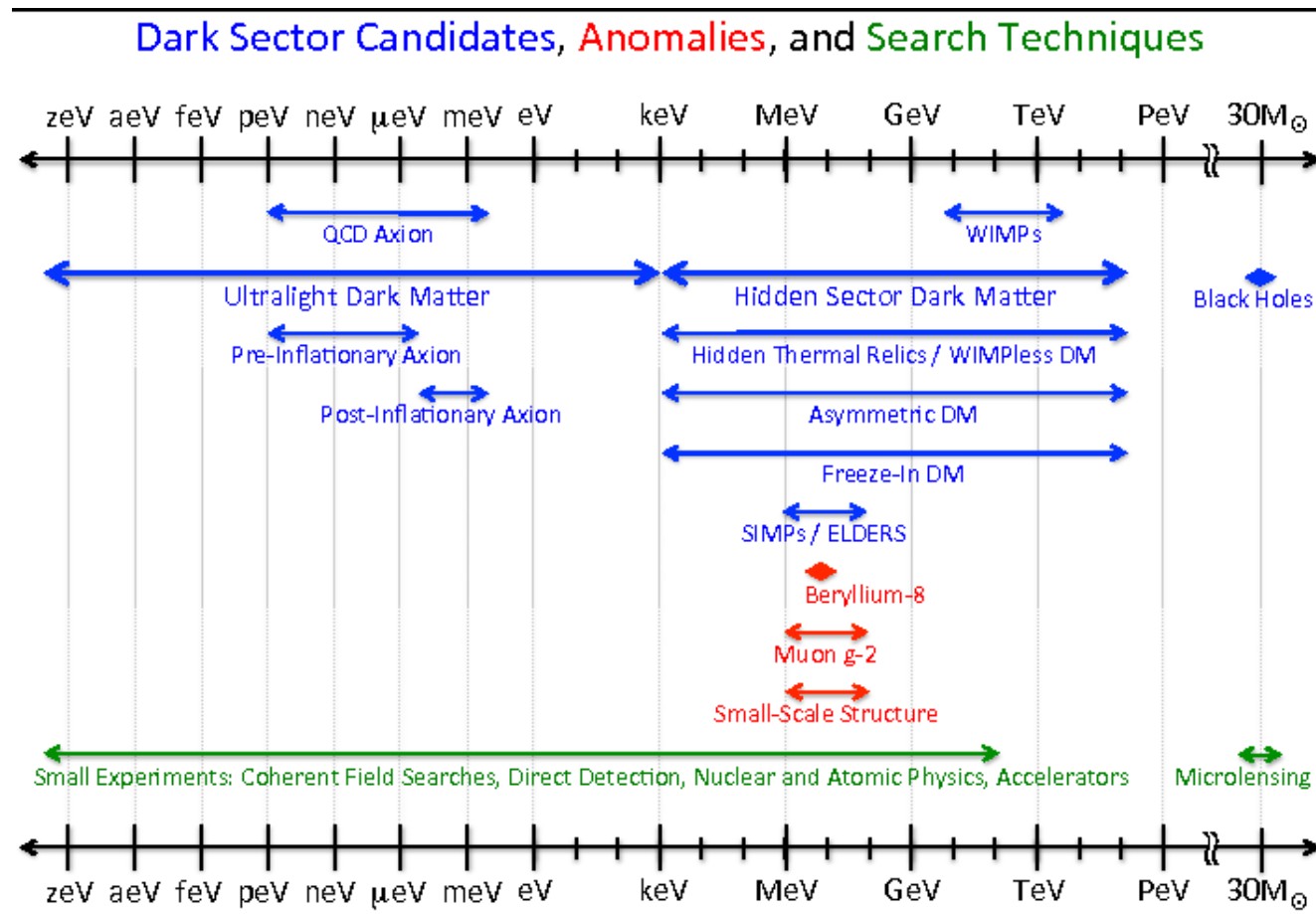


Dark Matter Particle

- The primary candidate for a long time was the WIMP, but it is almost completely ruled out.
- SuperCDMS is looking for a particle with a **weak interaction cross-section**, combined with a mass range of the neutralino between 10 - 100 GeV.
- Prime candidates include neutrinos, axions, and neutralinos.

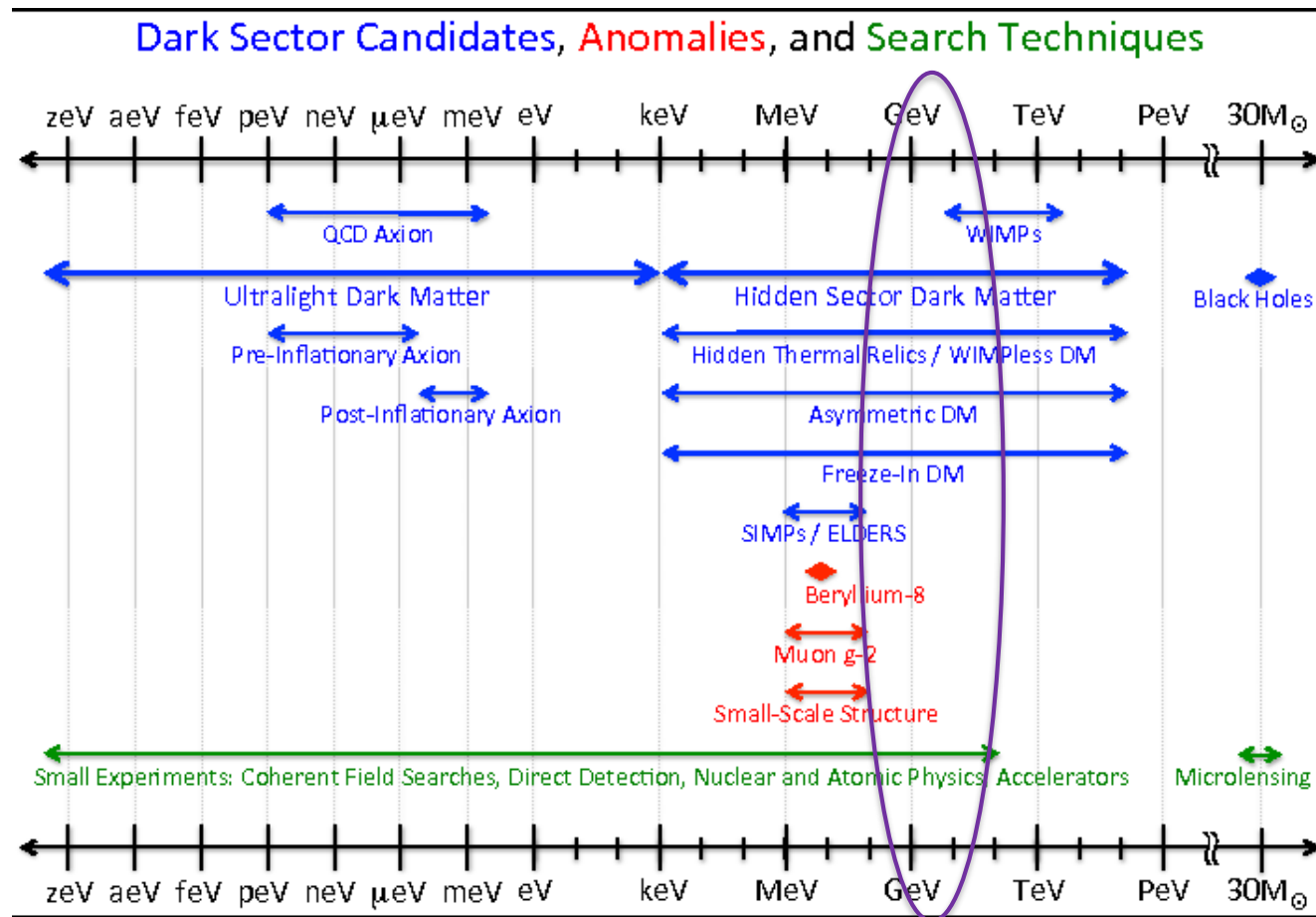


Dark Matter Particle



- Above keV=Fermions (electrons, neutrinos)
- Below keV= Bosons (photons, pions)

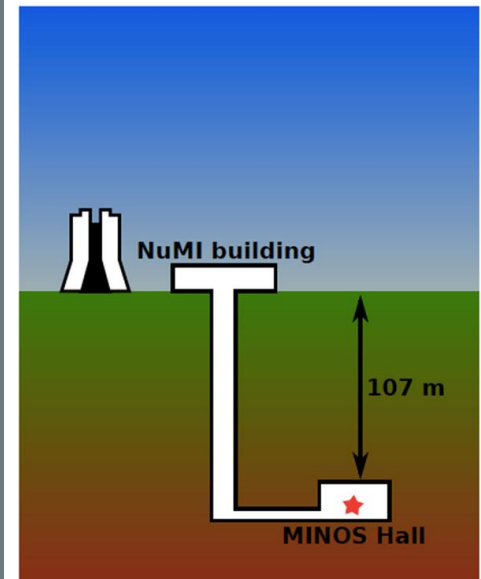
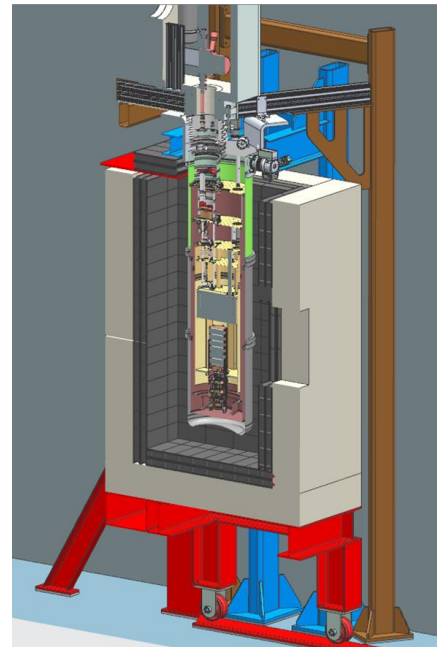
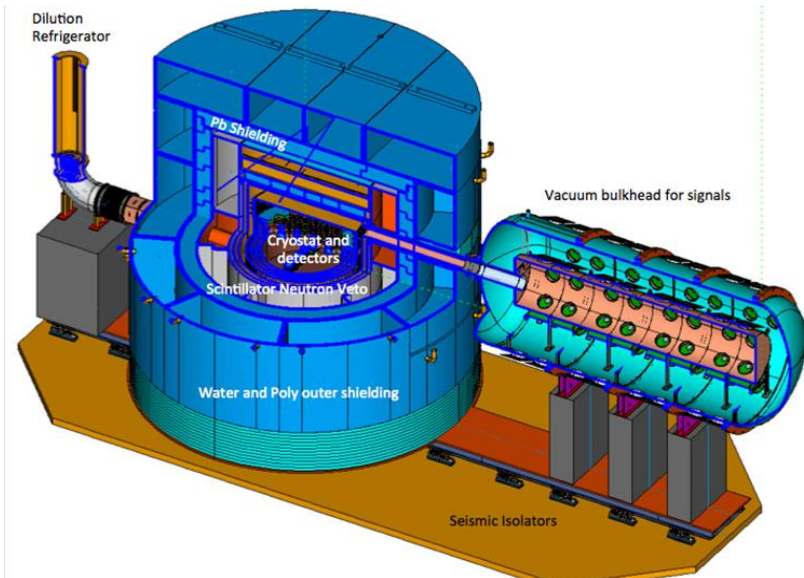
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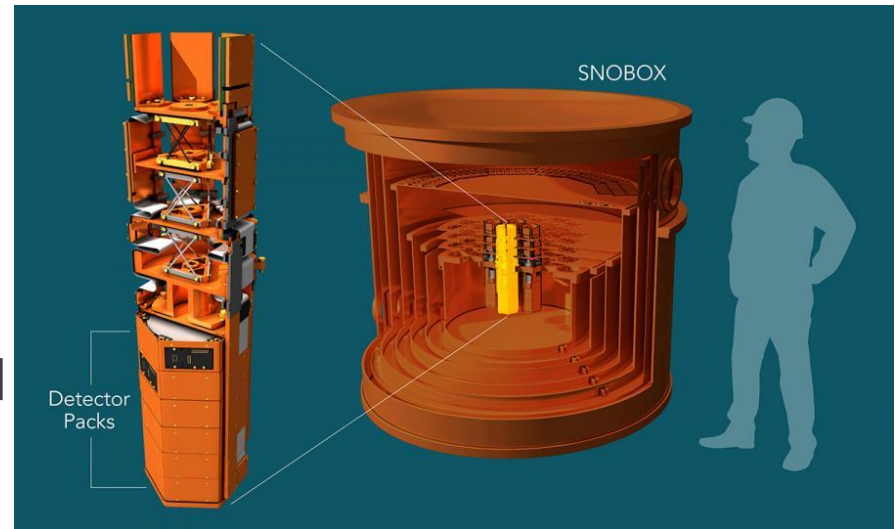
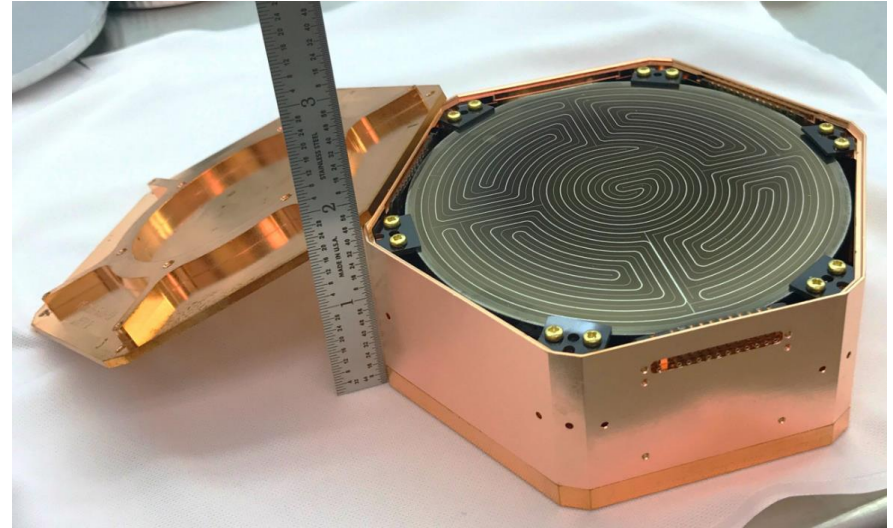
SuperCDMS & NEXUS

- CDMS stands for Cryogenic Dark Matter Search
 - Looks to directly detect low mass ($< 10 \text{ GeV}/c^2$) WIMPs by using silicon and germanium crystal detectors.
- The NEXUS test Facility is located underground in Minos Hall.
 - Plan to aid in the cryogenic and performance testing of the CDMS detector system.



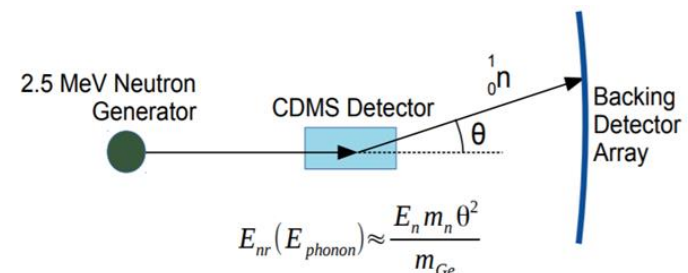
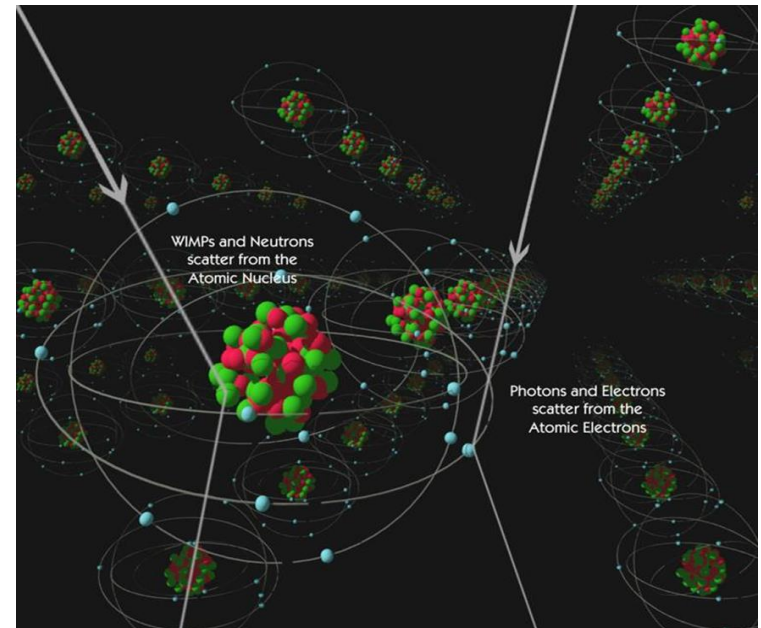
SuperCDMS Detector

- The series of detector packs is shielded by various enclosures that aid in preventing excess background noise from getting in.
- Each layer inside the SNOBOX will become increasingly cooler to reach a fraction above absolute zero.
 - The outermost layer will be about 300 K (room temp) and the innermost layer will be around 30 mK.



SuperCDMS Detector

- The detector is expected to be one of the most sensitive DM detectors to date.
 - Composed of Si and Ge crystals.
- Dark matter particles can be detected if they scatter off nuclei as they cause vibrations (phonons) and ionization in the detectors.
 - The backing array catches neutrons that are recoiled. (Cross Check/Calibration)

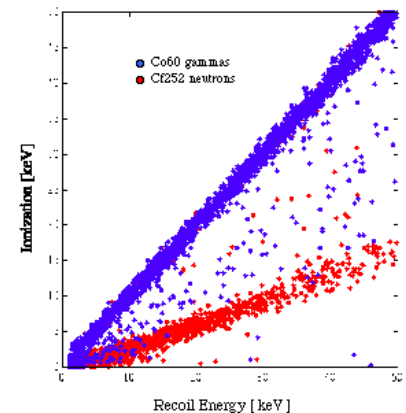


SuperCDMS Detector

- These detectors are **super** sensitive.
 - Great for finding potential dark matter particles!
 - WIMPs can scatter off both nucleus and electron, but photons scatter off as well.
- We can find ways to reduce the amount of light (including IR & UV) that can leak into the detector by creating a light-tight enclosure for the detectors.

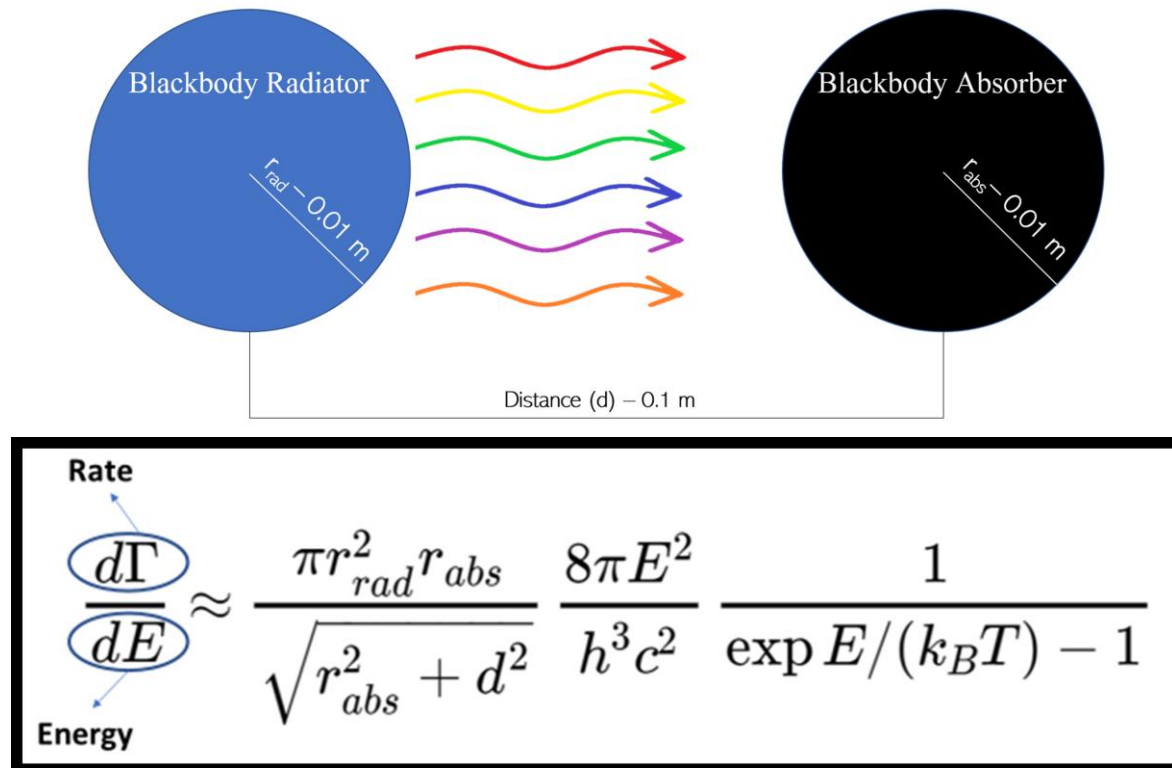
Nuclear Recoil Discrimination

- WIMPs produce nuclear recoils (weak charge of nucleus/kinematics)
- Background sources (photons, electrons, alphas) produce electron recoils
- Ionization yield (= ionization/unit recoil energy) strongly dependent on type of recoil

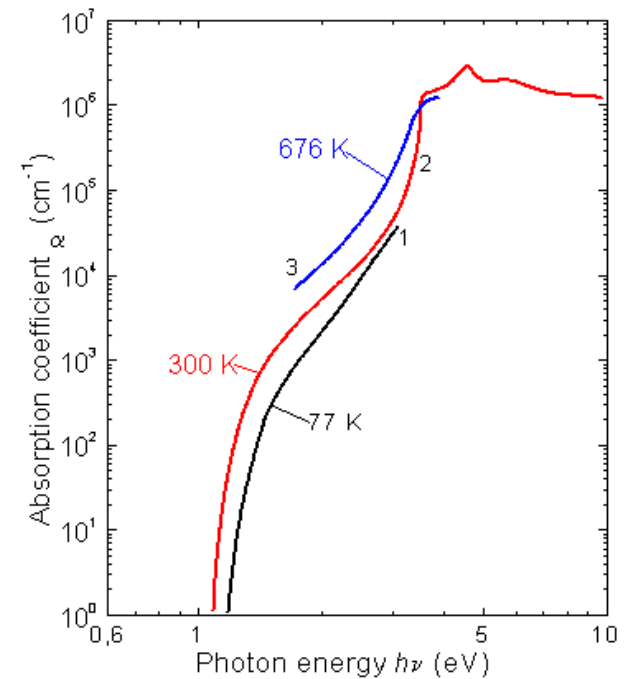
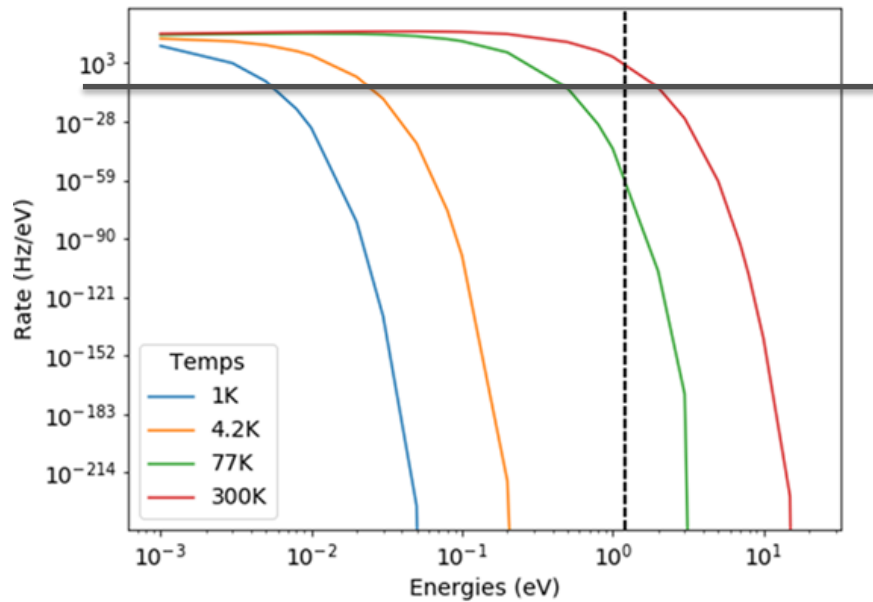


Light Leakage Models

- A blackbody is a theoretical object that **absorbs all incident electromagnetic radiation** while maintaining thermal equilibrium. No light is reflected from or passes through a blackbody, but **radiation is emitted**.



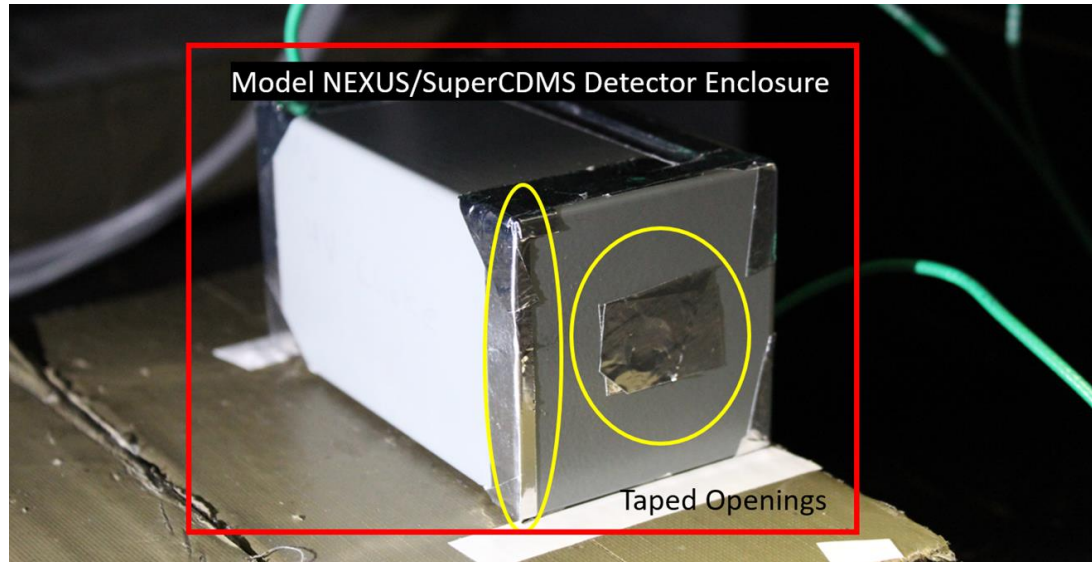
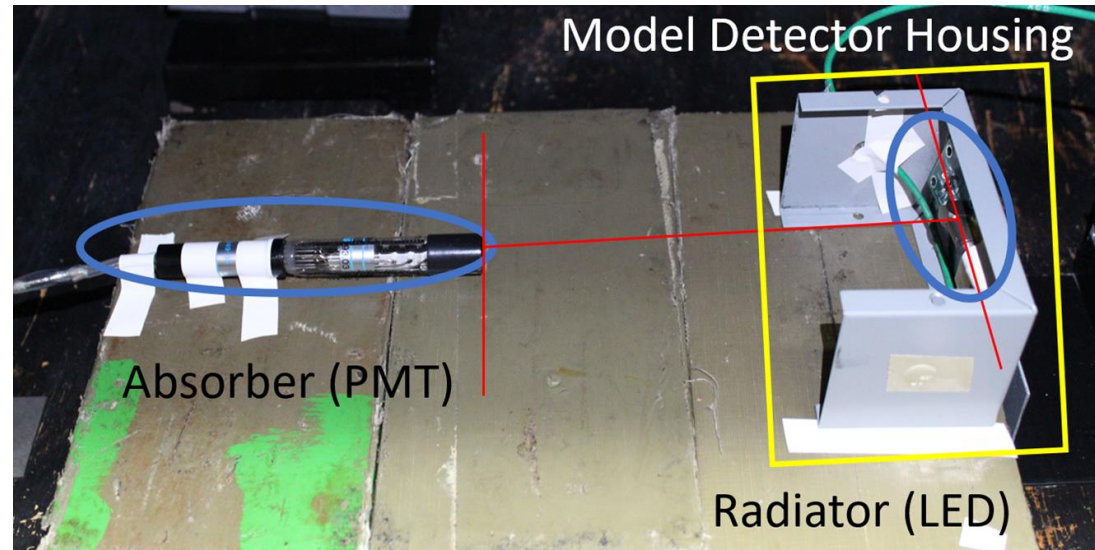
Light Leakage Models



- Figure shows the rate of photons that can leak into the detector.
 - The dotted line = minimum event energy of 1.2 eV.
 - Below this energy all light will pass through detectors with no read out.
 - Above this energy all light will be read out.

Experimental Set-up: Dark Box

- **First:** We set up the photomultiplier tube (PMT) in the dark box and recorded the number of dark hits and noise.
- **Second:** We set up the LED/PMT system in the dark box and recorded the amount of light emitted.

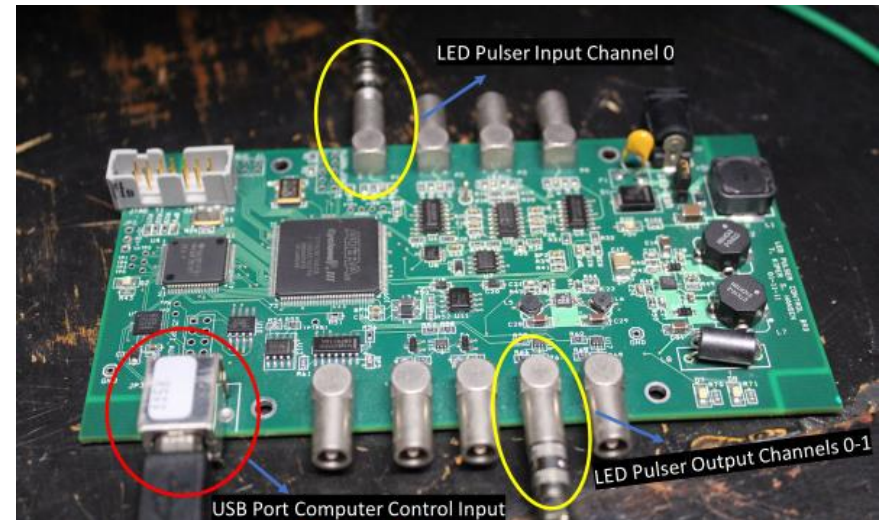
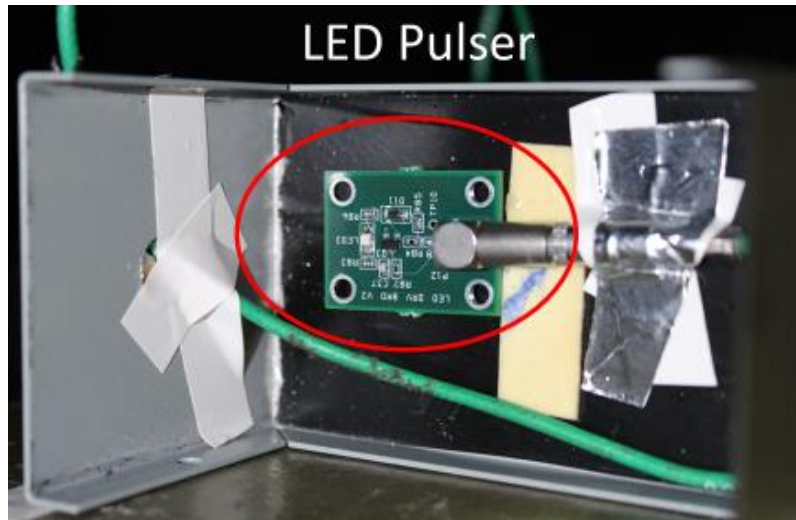


- **Third:** We added the LED/PMT system into the model detector box enclosure and adjusted any leakage with aluminum tape.
- **Fourth:** We retaped the model detector enclosure after opening it for other test runs (continued this process of retaping as tests continued).

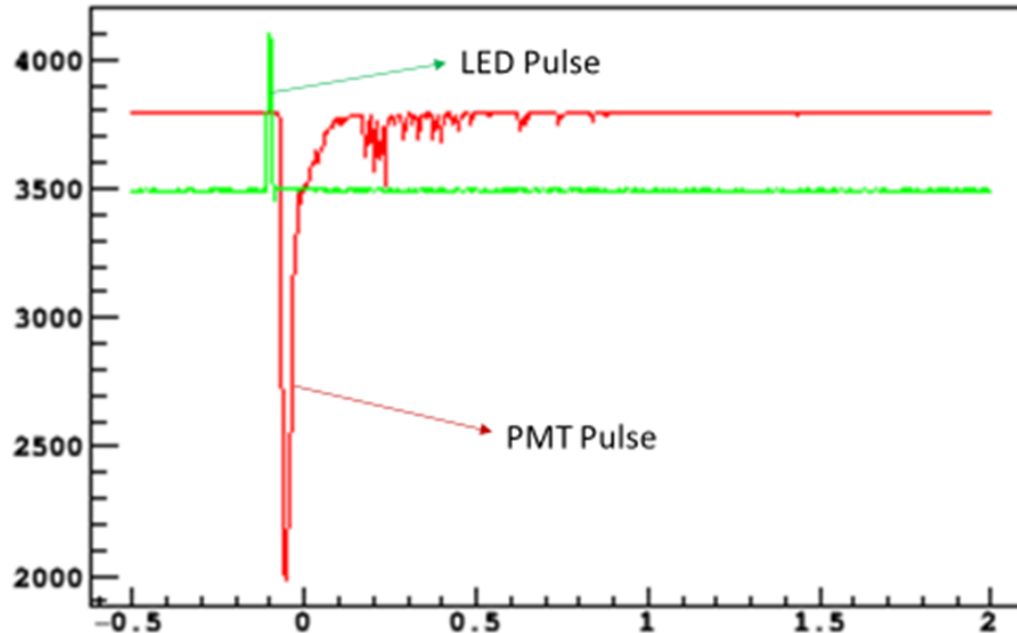
Experimental Set-up

LED Pulser Settings				
	100 Hz	100 Hz	1000 Hz	16670 Hz
Delay btw LED pulses (50 us/cnt)	1	1	1	1
LED Pulse Patterns per Sequence	1	100	1	100
Number of Sequences to Repeat	Cont.	Cont	Cont.	Cont.
Delay between each Sequence (ms)	10	995	1	1

- LED Pulser Settings affect the rate of flashes per second.
 - Aids in reducing the length of runs.

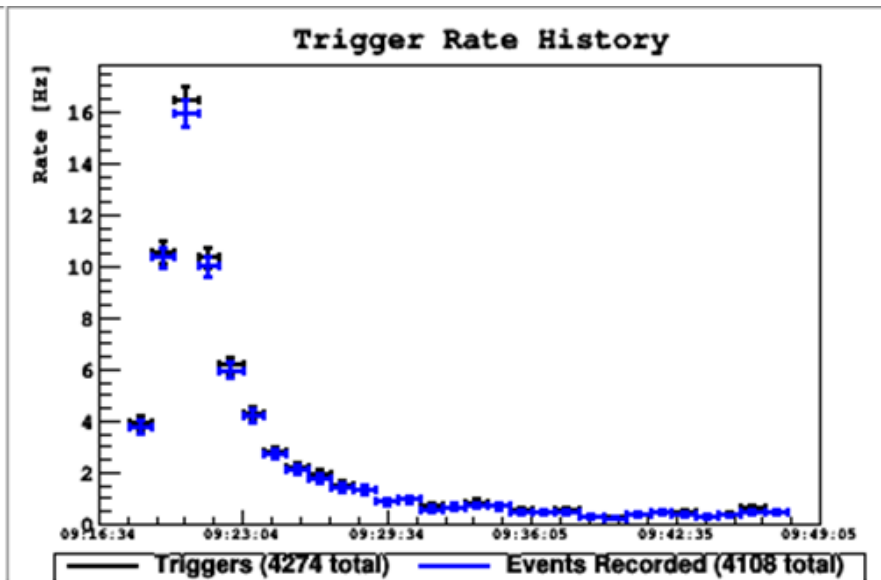
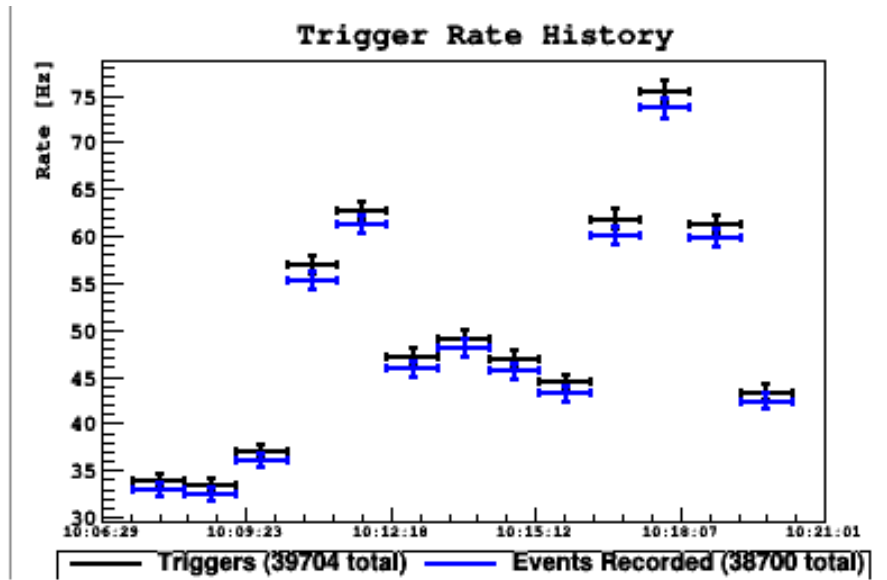


Experimental Results: LED & PMT



- Many tests taken, had the LED running in coincidence with the PMT.
 - One set of **background tests**, the LED tests, and the LED in the model enclosure tests.
- This means the PMT would trigger on the LED pulses in an 80 ns window.

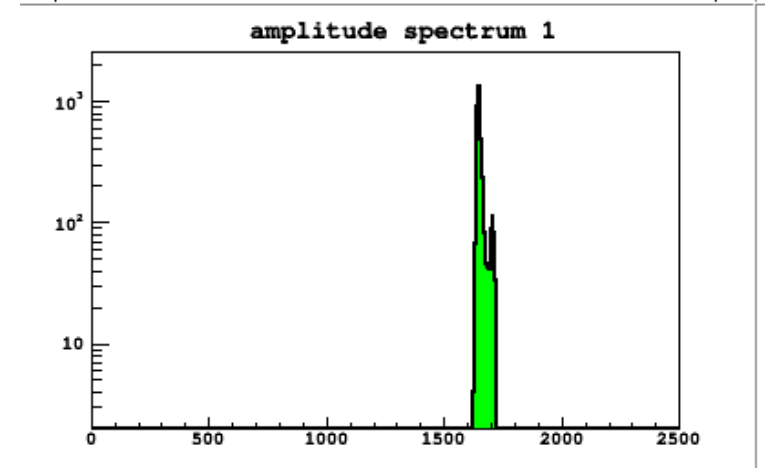
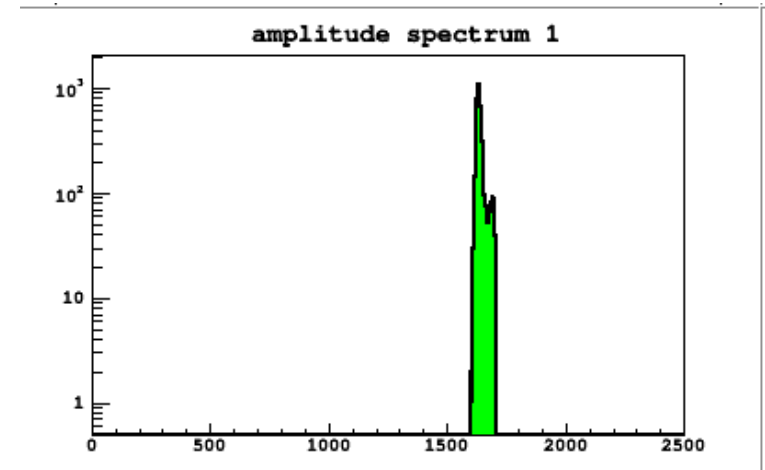
Experimental Results: Background



- Background fluctuation was initially a big problem when conducting the tests.
- The left figure was taken July 23rd and the right figure was taken July 29th.
- Left: 15 minutes (900 seconds), total 38700 events
- Right: 30 minutes (1800 seconds), 4108 events.

Experimental Results: LED Flashes

- The figures to the right show the same amplitude for each LED test (about 1000).
- This means there is a consistent response the PMT gets from the LED flashes.
 - This proves that the gain on the PMT was not changing.



Experiment Results: Trial 1

Trial 1: Background				
	Time	Events	Events/s	Expected BG Events/80 ns Window
<i>Run 1</i>	148	5028 ± 71	34 ± 0.5	$3\text{E-}6 \pm 4\text{E-}8$
<i>Run 2</i>	669	45187 ± 213	68 ± 0.3	$5\text{E-}6 \pm 2\text{E-}8$
<i>Run 3</i>	856	39543 ± 199	46 ± 0.2	$4\text{E-}6 \pm 2\text{E-}8$
TOTAL	1673	89758 ± 300	54 ± 0.2	$4\text{E-}6 \pm 2\text{E-}8$

TRIAL 1: LED Flash					
	Time	Flash Rate (Hz)	Number of Flashes	Events	Events/Flash
<i>Run 1</i>	228	100	22800	1	$4\text{E-}5$
<i>Run 2</i>	732	1000	732000	15	$2\text{E-}5$
<i>Run 3</i>	775	1000	775000	14	$2\text{E-}5$
TOTAL	1735	N/A	1529800	30	$2\text{E-}5$

- This is the first set of tests with the LED inside its model enclosure and the background tests taken before each run.
- Minimal holes were covered, and the rate of LED flashes was kept relatively low (100 Hz and 1000 Hz).

Experiment Results: Trial 2

Trial 2: Background				
	Time	Events	Events/s	Expected BG Events/80 ns Window
<i>Run 1</i>	1371	3925 ± 63	3 ± 0.05	$2\text{E-}7 \pm 4\text{E-}9$
<i>Run 2</i>	852	44781 ± 212	53 ± 0.2	$4\text{E-}6 \pm 2\text{E-}8$
<i>Run 3</i>	3061	116284 ± 341	38 ± 0.1	$3\text{E-}6 \pm 8\text{E-}9$
TOTAL	5284	164990 ± 406	31 ± 0.08	$2\text{E-}6 \pm 6\text{E-}9$

TRIAL 2: LED Flash					
	Time	Flash Rate (Hz)	Number of Flashes	Events	Events/Flash
<i>Run 1</i>	1350	1000	1350000	0	0
<i>Run 2</i>	1062	1000	1062000	9	$8\text{E-}6$
<i>Run 3</i>	1074	100	107400	9	$8\text{E-}5$
TOTAL	3486	N/A	2519400	18	$7\text{E-}6$

- This is the second set of tests of the LED inside its model enclosure and the background tests taken before each run.
- All holes and cracks that could be seen were taped (similar to the picture on slide 9), and the rate of LED flashes was kept relatively low again (100 Hz and 1000 Hz).

Experiment Results: Trial 3

Trial 3: Background				
	Time	Events	Events/s	Expected BG Events/80 ns Window
<i>Run 1</i>	1071	276 ± 17	0.3 ± 0.02	$2\text{E-}8 \pm 2\text{E-}9$
<i>Run 2</i>	813	202 ± 14	0.2 ± 0.02	$2\text{E-}8 \pm 2\text{E-}9$
<i>Run 3</i>	687	212 ± 15	0.3 ± 0.02	$2\text{E-}8 \pm 2\text{E-}9$
TOTAL	2571	690 ± 26	0.3 ± 0.01	$2\text{E-}8 \pm 8\text{E-}10$

Trial 3: LED Flash					
	Time	Flash Rate (Hz)	Number of Flashes	Events	Events/Flash
<i>Run 1</i>	3847	16670	64129490	4	$6\text{E-}8$
<i>Run 2</i>	10541	16670	175718470	4	$2\text{E-}8$
<i>Run 3</i>	6779	16670	113005930	1	$9\text{E-}9$
TOTAL	21167	N/A	352853890	9	$3\text{E-}8$

- This shows the final tests of the LED inside its model enclosure and the background tests taken before each run.
- All holes and cracks that could be seen were retaped with thick aluminum tape, and the rate of LED flashes was increased significantly (16670 Hz).

Experiment: Final Results & Calculations

Final Calculations of All Trials					
	Total Events with LED Flashing	Total Number of Flashes	Total Events/Flash	Expected BG Events/80 ns Window	Calculated LED Events
<i>Trial 1</i>	30 ± 5.5	1529800	$2\text{E-}5 \pm 0.36\text{E-}5$	$4\text{E-}6 \pm 0.02\text{E-}6$	$1.6\text{E-}5 \pm 0.36\text{E-}5$
<i>Trial 2</i>	18 ± 4.2	2519400	$7\text{E-}6 \pm 1.7\text{E-}6$	$2\text{E-}6 \pm 0.006\text{E-}6$	$5\text{E-}6 \pm 1.7\text{E-}6$
<i>Trial 3</i>	9 ± 3	352853890	$2.6\text{E-}8 \pm 0.85\text{E-}8$	$2\text{E-}8 \pm 0.08\text{E-}8$	$5.5\text{E-}9 \pm 8.54\text{E-}9$

- This chart is representative of all three trials and includes important calculations.
- Expected BG Events/80 ns Window is taken from each background trial and the **Calculated LED** events comes from the Expected BG events/80 ns window subtracted from the Total Events/Flash.
- Trials 2 & 3 are consistent with the expected background.

Experiment: Final Results & Calculations

Final Calculations of All Trials					
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<i>Trial 2</i>	18 ± 4.2	2519400	$7\text{E-}6 \pm 1.7\text{E-}6$	$2\text{E-}6 \pm 0.006\text{E-}6$	$5\text{E-}6 \pm 1.7\text{E-}6$
<i>Trial 3</i>	9 ± 3	352853890	$2.6\text{E-}8 \pm 0.85\text{E-}8$	$2\text{E-}8 \pm 0.08\text{E-}8$	$5.5\text{E-}9 \pm 8.54\text{E-}9$

Calculated LED Events
$1.6\text{E-}5 \pm 0.36\text{E-}5$
$5\text{E-}6 \pm 1.7\text{E-}6$
$5.5\text{E-}9 \pm 8.54\text{E-}9$

- There is a significant decrease in events from Trial 1 to Trial 3. There are about 30 events in 1529800 flashes, compared to 9 events in 352853890 flashes.
- The last column in Figure 19 shows the amount of calculated LED events going down by a factor of 10000 (from $1.6\text{E-}5$ to $5.5\text{E-}9$).

Conclusion & Future Work

- The background went down as the runs continued.
- As tape was added, there was a significant decrease in the amount of light leakage.
- These tests provide us with a procedure to test light attenuation in the detector enclosure.
 - This reduces the time spent testing the enclosure for background.
 - 1 week in dark box vs 6 months in fridge/detector system
- Future tests include testing the actual detector enclosure in the dark box with the fiber that runs out from the detector to the outside of the housing.

Special Thanks to...

- **Advisors/Supervisors:** Noah Kurinsky, Lauren Hsu, and Dan Bauer
- **Mentors:** Michael, Andrew, and Alex
- Sandra Charles and Judy Nunez
- SIST-ers and GEM fellows
- All the other scientists I have met with and learned from this summer

